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16. ABSTRACT

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Exhaust and evaporative emissions were examined from vehicles fueled with methanol or a gasoline-methanol blend. Regulated automobile pollutants, as well as detailed hydrocarbons, methanol, and aldehydes were measured, and exhaust emission trends were obtained for vehicle operation over five different driving cycles. Results indicated that use of the blended fuel does not generally have any significant effect on base-line exhaust emission rates of regulated pollutants; however, emission rates of aldehydes increased during the Federal Test Procedure. Aldehyde emissions from the methanol-fueled car were roughly an order of magnitude higher than those resulting from blended fuel usage. The hydrocarbon composition of evaporative emissions with the blended fuel was similar to that with the base-line fuel except when canister breakthrough occurred. Evaporative emissions during breakthrough were comprised chiefly of *N*-butane.

Use of methanol as a fuel in motor vehicles has become a popular issue in the automotive and petroleum industries. Methanol from natural gas is generally regarded as an economical source of energy; eventually, methanol from coal is projected to be even cheaper. Because tapping large natural gas surpluses and extensive coal reserves in the United States could further alleviate our dependence upon foreign oil, an increased use of methanol fuel would seem a reasonable course to take. In addition to these positive energy-related attributes, the alleged clean burning characteristics of methanol portray it as an environmentally attractive fuel.

Methanol use is not without its problems, however. Vehicles burning neat methanol tend to produce exhaust emissions that contain relatively high levels of formaldehyde and methanol. There is also evidence that use of methanol blends reduces canister effectiveness in control of evaporative emissions from gasoline vehicles.[1,2] Research is being conducted to more fully understand these and other problems associated with use of methanol in automobiles.

This study provides results which contribute to a better understanding of exhaust and evaporative emissions from vehicles operating on methanol and methanol blends. Exhaust and evaporative emissions were examined from two vehicles fueled with a methanol blend and from one fueled with methanol. In addition to regulated automobile exhaust pollutants, which include hydrocarbons (HC), carbon monoxide (CO), and nitrogen oxides (NO_x), detailed hydrocarbons, methanol, and aldehydes were examined. Exhaust emission trends were obtained for vehicle operation over five different driving schedules having average speeds ranging from 7 to 48 miles per hour. Both diurnal and hot soak evaporative emissions were measured and characterized for detailed hydrocarbon and methanol emissions.

Experimental Procedures

Test Vehicles

The three test vehicles used in this study are described in Table I. All were equipped with throttle-body fuel injection systems. The Mustang and Cavalier, which have gasoline-fueled engines, were used to examine emissions resulting from use of gasoline-methanol blends. Both were low mileage vehicles that had been rented from a local vendor. The Mustang had a V-6, 3.8-liter engine with a closed loop, 3-way plus oxidation catalyst emission control system. The Cavalier had a 4-cylinder, 2-liter engine with a 3-way catalyst emission control system.

The Methanol Ford Escort was a modified version of its gasoline-fueled counterpart. Ford's approach to modifying the engine for methanol consumption has been to retain as many as possible of the gasoline Escort features. Its engine is a 1.6- liter, 4-cylinder configuration, with an overhead camshaft and hemispherical combustion chamber. Compression ratio has been increased to 11.4:1 to benefit from the high octane quality of methanol. Because theoretical A/F ratio for methanol is 6.4 versus 14.5 for gasoline, the carburetor has been recalibrated to deliver larger quantities of fuel. Ignition timing has also been optimized to account for changes in compression ratio and higher flame speed of methanol.

Many of the parts in the Escort's fuel tank and fuel delivery system have been modified to withstand the corrosive nature of methanol. Parts coming into contact with methanol are constructed from resistant materials such as stainless steel, tin, zinc, electroless nickel plate, and dichromate.[3]

The Escort on loan from EPA-Ann Arbor, was purchased new shortly before the program started. After delivery of the car, problems with engine backfire and loss of power were noted. Engine backfiring, caused by preignition in methanol-fueled engines, has been reported by other investigators.[4–6] However, the loss of power resulted from a severely plugged catalytic converter. The suspected cause of the plugging was poor combustion resulting from contaminated fuel usage. Thus, before testing resumed, the fuel system was flushed, the fuel pump re-

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placed, and a new catalyst supplied by Ford was installed. Following these repairs the Escort ran satisfactorily for the duration of the test program.

Fuel Description

A description of the fuels used in this study is given in Table II. "Base-line" fuel was used to examine base-line emissions from the Cavalier and Mustang. This fuel was a commercial, unleaded premium gasoline. Base-line fuel was also used as the gasoline component for the "blended" and "methanol" fuels.

The blended fuel consisted of about 90% gasoline/5% methanol/5% tertiary butyl alcohol (TBA). The TBA acted as a co-solvent to increase the solubility of methanol and water in the finished gasoline and decrease the possibility of phase separation.

The "methanol" fuel used in the Escort was a mixture of 90% methanol/10% unleaded gasoline. The gasoline portion is required to provide good front-end volatility for cold start. The fuel was prepared at EPA and was dispensed to the vehicle using equipment recommended by Ford for use with methanol.

Facility Description

All exhaust emission tests were conducted with a chassis dynamometer for vehicle road load simulation. The dynamometer (Horiba Instruments, Inc.) simulated road load by means of a DC electric motor-generator directly coupled to the front rolls of the dynamometer.

Exhaust gases from the test vehicle were directed via a 7.6-cm (3-in.)-diameter, flexible stainless steel line to a 20.3-cm (8-in.)-diameter dilution tunnel (Figure 1). Within the dilution tunnel, raw exhaust gas was thoroughly mixed with filtered diluent and the diluted mixture drawn through the system by a positive displacement pump located downstream. Flow rate through this constant volume system (CVS) was maintained around 650 scfm. Gas samples were collected in dilute exhaust gas within the tunnel.

Evaporative emissions from the vehicles were sampled using a SHED (Sealed Housing for Evaporative Determination) technique. The vehicle was pushed into an enclosure that can be sealed by closing a large pneumatically controlled door. Evaporative emissions from the vehicle inside the enclosure were monitored with a hydrocarbon analyzer, and gas samples drawn off into 10-liter Tedlar bags were analyzed for methanol and detailed hydrocarbons.

Table I. Description of test vehicles.

Feature	Ford Mustang 1984	Chevrolet Cavalier 1984	Methanol Escort 1983
Number of doors	2	4	4
Odometer, miles	1000	4500	1500
Number of cylinders	V-6	4	4
Displacement, liters	3.8	2.0	1.6
Fuel system	Throttle-body fuel injection	Throttle-body fuel injection	Throttle-body fuel injection
Catalyst	3-way + Oxy.	3-way	3-way
Control loop	Closed	Closed	Open
Inertia test wt., lb.	3500	2750	2500
Road load, HP at 50 mph	10.3	5.7	6.0

Table II. Description of test fuels (fuel codes in parentheses).

Property	Base-line (B-100)	Blended (MEOH/TBA-10)	Methanol (MEOH-90)
% Methanol		4.5	90
% TBA		5.7	
Gravity, API	59.5		70
Reid vapor press, psig	11.7	12.9	7.0
% Evap @			
60°C			5
63.5°C			80
65°C	22	35	95
118°C	57	63	
190°C	92	91	
End point, °C	215	222	67
% Recovered	97.0	98.0	98.0
% Residue	1.2	1.0	1.3
% Saturates	64.1		
% Olefins	6.1		
% Aromatics	29.8		
% Carbon	85.7		
% Hydrogen	13.7		

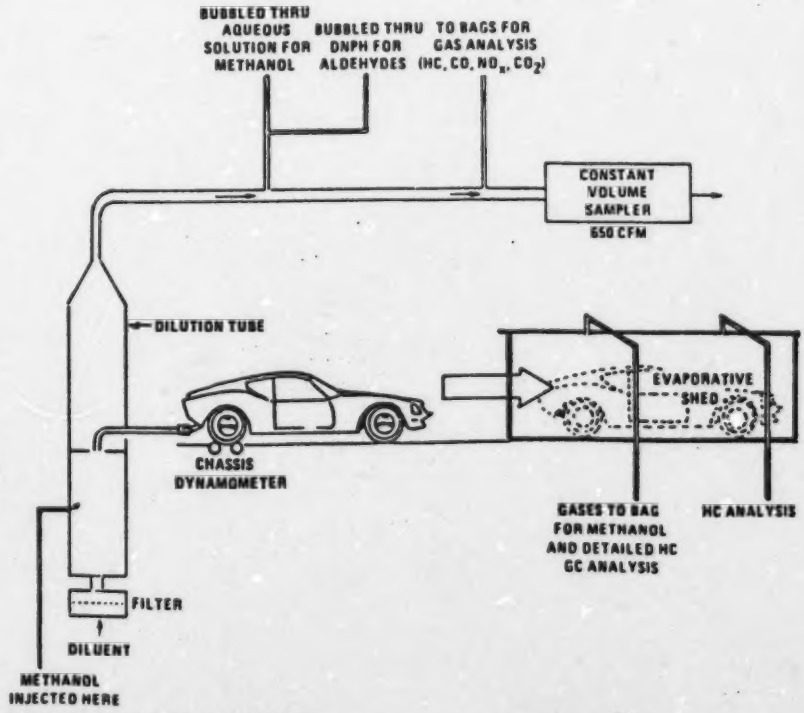

Figure 1. Auto exhaust sampling scheme.

Gaseous Emission Measurement

Emissions were examined for both regulated (HC, CO, and NO_x) and nonregulated pollutant emissions in this test program. Nonregulated pollutants examined were methanol, formaldehyde, and detailed hydrocarbons.

Methanol in dilute CVS gas was sampled by bubbling the gas through two series impingers containing about 25 mL of water apiece. Because methanol is highly soluble in water, it was effectively trapped in the water solution. After the test was completed, the methanol samples were analyzed in a gas chromatograph (GC). A description of this method has been published.[7]

Methanol in evaporative emissions was sampled as a gas drawn off into a 10-liter Tedlar sample bag. Later, the contents of the bag were bubbled through impingers containing water. Analysis of methanol trapped in aqueous solution was then accomplished by gas chromatography.

Aldehydes in dilute exhaust gas were collected in an impinger containing a solution of acidic 2,4-dinitrophenylhydrazine (DNPH). The aldehydes reacted with the solution to form the 2,4-dinitrophenylhydrazone aldehyde derivative. After the test was completed, the solution containing the derivatives in acetonitrile was injected into a high performance liquid chromatograph (HPLC) for analysis by a method described elsewhere.[8] The HPLC method allows identification of more aldehydes and detection of lower levels than the GC procedure currently in use in our laboratory.[9] It is also being used in conjunction with a simplified sampling technique that replaces impingers with cartridges.[10]

Both methanol and aldehyde exhaust-gas sampling procedures permitted examination of the CVS diluent background. Background levels were simply subtracted from levels measured in the exhaust during the test.

Detailed hydrocarbon analyses were performed using the chromatographic procedures of Black *et al.*[11] These procedures permitted identification and quantification of 95% of the total emitted hydrocarbons. Eighty different chromatographic peaks were reported detailing the C_1 through C_{10} hydrocarbons. A computer system interfaced to the GC facilitated rapid identification and quantification of the various peaks.

With the exception of hydrocarbons, regulated exhaust and evaporative emissions were determined using standard sampling and analysis procedures in accordance with the *Federal Register*.[12] A separate procedure was used to determine hydrocarbons in exhaust gas containing methanol. Because the flame ionization detector (FID) used to analyze hydrocarbons has a lower relative response to methanol than to hydrocarbons, values for the latter, reported as "non-methanol hydrocarbons," were determined by subtracting the response due to the methanol fraction from the total hydrocarbon response. The methanol response was found by multiplying the FID methanol response factor by the concentration of methanol in the sample. The methanol concentration of samples was determined using the impinger/GC procedure previously described; FID response factor was obtained through a separate set of experiments involving methanol injections.

Methanol Injection Experiments

The methanol injection data are summarized in Table III. Methanol was injected at three different rates into the CVS system. Six injection tests produced methanol concentrations of about 10 ppm, seven of about 50 ppm, and four of about 150 ppm. Each exact concentration was calculated by measuring the volume of methanol injected and the volume of the CVS dilution air. During each injection period, bag samples for FID analysis and impingers for GC analysis were collected simultaneously. FID methanol response factors were first obtained using actual methanol concentrations calculated from measurements of injected methanol in known volumes of diluent. Another set of response factors was obtained using methanol concentrations measured with the impinger/GC method. Because the impinger/GC measurements approximated those calculated from measured volumes, the two sets of response factors are very nearly equal. These values, ranging from 0.73 to 0.76 are in close agreement with those observed in previous studies.[13,14]

Table III. Methanol injection summary.

No. of tests	MeOH Conc. by CVS volume [A]	Impinger/GC conc. [B]	Bag/FID conc.[a] [C]	FID response factor calculated as [C]/[A]	FID response factor calculated as [C]/[B]
6	9.8	9.4	7.2	0.73	0.76
7	51.6	52.4	38.0	0.74	0.73
4	152.8	159.1	115.5	0.76	0.73

[a] Corrected for background.

Table IV. Test sequence.

Week No.	Event	Frequency	Data collected
1	Prep vehicle	Mon.	None
	Fuel vehicle	Tues.–Fri.	None
	Diurnal evap. test	Tues.–Fri.	Detailed HC, HC, methanol
	FTP	Tues.–Fri.	Methanol, aldehydes, detailed HC, HC, CO, NO_x, CO_2
	Hot soak evap. test	Tues.–Fri.	Detailed HC, HC, methanol
2	Prep vehicle	Mon.–Fri.	None
	HFET	Mon.–Fri.	Same as for FTP
	NYCC	Mon.–Fri.	Same as for FTP
	SCC-12	Mon.–Fri.	Same as for FTP
	SCC-36	Mon.–Fri.	Same as for FTP
3	Repeat Week 1		
4	Repeat Week 2		

Run Schedule and Cycle Descriptions

Test vehicles were operated in similar test plans, which were designed to obtain an emissions characterization for five different driving cycles and two evaporative tests. The gasoline-fueled cars were tested first on base-line fuel, then on blended fuel. Table IV shows the test sequence and sampling effort followed for each car-fuel combination tested. An exception to this was made during a portion of testing on the Mustang in order to more comprehensively examine the evaporative emissions phenomenon.

A brief description of each of the test cycles is given in Table V. The Federal Test Procedure (FTP) and Highway Fuel Economy Test (HFET) are well-known cycles with previously published descriptions.[15–17] The Speed Correction Cycles (SCC-12 and SCC-36), which have average speeds of 12 mph and 36 mph, are excerpted from the FTP and Congested Freeway Driving Schedule. Both were used to obtain emission factors at average speeds for which data were needed. Combined

Table V. Test cycle descriptions.

Test cycle	Cold start	Avg. speed (mph)	Stops per mile	Total distance (mi)	Duration (min)	% Idle
FTP	Yes	21.3	2.40	11.1	31.3	19.0
HFET	No	48.2	0.20	10.2	12.7	0.8
NYCC	No	7.1	9.32	1.2	10.0	40.2
SCC-12	No	12.1	5.11	1.2	5.8	27.2
SCC-36	No	35.9	0.21	9.5	15.9	2.7

with the New York City Cycle (NYCC), which has an average speed of 7.1 mph, the above cycles cover a broad range of average speed conditions.

Results and Discussion

Blended Fuel Exhaust Emissions

The effect of blended fuel on emissions was determined for two cars, a Mustang and a Cavalier, and five driving cycles. Exhaust emissions were compared using the base-line and blended fuels. Data summaries, which depict Mustang and Cavalier emission rates with the base-line and blended fuel, are presented in Tables VI and VII.

When run on the baseline gasoline, regulated exhaust emissions (HC, CO, and NO_x) from the Mustang exceeded 1984 emission standards for light-duty vehicles. Compared with the standard level values of 0.41 g/mi, 3.4 g/mi, and 1.0 g/mi for HC, CO, and NO_x, respectively, the FTP levels were 0.68 g/mi, 6.22 g/mi, and 1.74 g/mi. No extensive effort was made to determine the source of the problem because vehicle performance was otherwise satisfactory. Emission levels from the Cavalier were lower than those from the Mustang, as expected, because the Cavalier was selected for testing after being screened for compliance with the standards.

Generally, regulated exhaust emission rates were about the same for both the base-line and blended fuels. Statistically significant differences were observed for both cars only with the NYCC where average NO_x emission rates were about 30% higher when the vehicles were tested with the blended fuel. The confidence level of this observation was >95% for the Mustang and >99% for the Cavalier.

Exhaust methanol emissions were not detected during the base-line-blended methanol fuel study. The limit of detection for the impinger/GC method was about 0.1 ppm methanol. The most likely period that methanol would have been detected was during the Bag 1 (cold transient) phase of the FTP. Had 0.1 ppm been detected in Bag 1, the FTP methanol emission rate would have been about 2 mg/mi. Therefore, it can be concluded that FTP methanol emissions were probably less than 2 mg/mi for the blended fuel tested.

Aldehyde emissions appeared to be fuel dependent for at least three test conditions. Use of the blended fuel resulted in higher aldehyde emissions during the FTP (both cars) and during the SCC-36 (Mustang only). For the FTP, both cars emitted roughly 50% more, and for the SCC-36, the Mustang emitted about twice as much aldehyde. A statistically significant twofold increase in formaldehyde emissions was also noted for the Mustang during the NYCC. Confidence levels supporting the observed increases in aldehyde and fromaldehyde emissions were >95% and 90%, respectively.

Aldehyde emissions trends associated with the Mustang were clearer than those from the Cavalier. Because emissions from the Cavalier often approached background levels, relative standard deviations (RSD) were high, and trends were not clear. On the other

Table VI. Comparison of emissions and fuel economy for Cavalier, baseline fuel vs. blended fuel.

Test procedure		Tailpipe emissions: HC, g/mi Base fuel	HC, g/mi Blended fuel	CO, g/mi Base fuel	CO, g/mi Blended fuel	NO_x, g/mi Base fuel	NO_x, g/mi Blended fuel	Aldehydes, mg/mi Base fuel	Aldehydes, mg/mi Blended fuel	Fuel economy, miles/gal. Base fuel	Fuel economy, miles/gal. Blended fuel
FTP	$\bar{x}$	0.19	0.15	3.00	2.84	0.41	0.41	2.40	3.37	23.80	24.05
	s	0.04	0.01	0.31	0.55	0.03	0.02	0.66	0.56	0.13	0.40
HFET	$\bar{x}$	0.01	0.01	0.16	0.40	0.21	0.23	0.10	0.64	35.47	36.32
	s	0.00	0.00	0.01	0.31	0.03	0.05	0.00	0.59	0.55	1.01
NYCC	$\bar{x}$	0.14	0.14	6.68	5.64	0.73	0.95	3.40	0.95	12.97	12.35
	s	0.03	0.03	0.78	2.17	0.11	0.05	2.26	1.28	0.37	0.49
SCC-12	$\bar{x}$	0.27	0.32	2.47	1.79	0.67	0.95	2.25	4.77	18.98	18.44
	s	0.04	0.06	0.39	0.16	0.09	0.24	1.76	3.65	0.31	0.76
SCC-36	$\bar{x}$	0.05	0.04	1.48	0.84	0.33	0.39	0.15	0.48	31.82	31.13
	s	0.02	0.01	1.01	0.16	0.04	0.05	0.21	0.55	1.67	1.22

Table VII. Comparison of emissions and fuel economy for Mustang, baseline fuel vs. blended fuel.

Test procedure		Tailpipe emissions: HC, g/mi Base fuel	HC, g/mi Blended fuel	CO, g/mi Base fuel	CO, g/mi Blended fuel	NO_x, g/mi Base fuel	NO_x, g/mi Blended fuel	Aldehydes, mg/mi Base fuel	Aldehydes, mg/mi Blended fuel	Fuel economy, miles/gal. Base fuel	Fuel economy, miles/gal. Blended fuel
FTP	$\bar{x}$	0.68	0.55	6.22	6.45	1.74	1.76	6.50	10.26	16.86	17.17
	s	0.16	0.05	0.56	1.15	0.21	0.09	1.22	2.11	0.17	0.12
HFET	$\bar{x}$	0.16	0.15	4.95	4.13	0.97	1.20	0.50	0.67	24.94	25.14
	s	0.02	0.03	0.17	0.74	0.16	0.07	0.14	0.22	0.43	0.22
NYCC	$\bar{x}$	1.50	1.64	12.80	10.28	2.91	3.71	6.35	9.52	8.55	8.35
	s	0.35	0.26	2.98	0.72	0.13	0.25	2.47	2.45	0.29	0.17
SCC-12	$\bar{x}$	1.07	1.29	10.41	15.38	2.55	2.65	22.9	41.37	13.16	13.20
	s	0.08	0.36	3.00	2.72	0.03	0.46	8.48	13.66	0.83	1.10
SCC-36	$\bar{x}$	0.33	0.45	6.67	9.28	1.35	1.37	2.50	5.42	22.66	23.58
	s	0.00	0.07	1.03	1.11	0.05	0.08	0.00	1.00	0.36	0.28

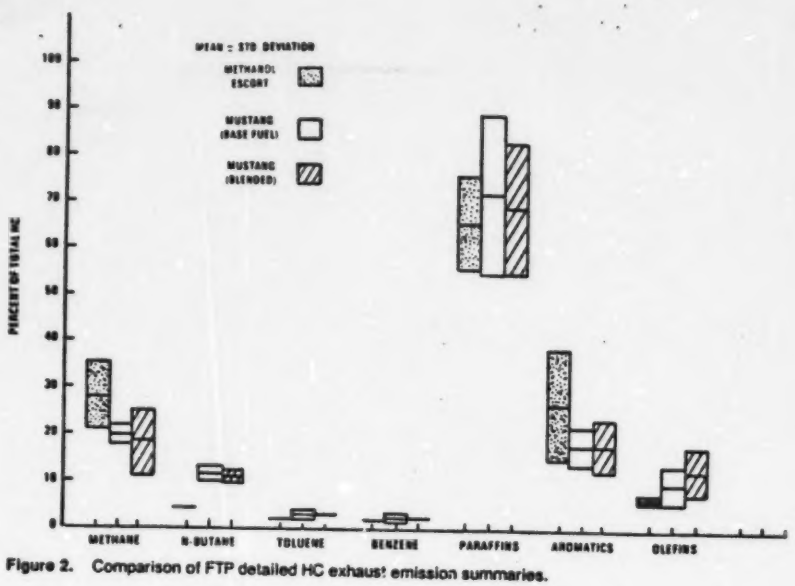

Figure 2. Comparison of FTP detailed HC exhaust emission summaries.

hand, standard deviations in the Mustang data were low (average RSD less than 25%), and the tendency toward increased aldehyde emissions with use of the blended fuel was more apparent. Most of the aldehyde emission increase was formaldehyde. In the FTP case, for example, the Mustang's 4-mg/mi aldehyde increase includes a 3-mg/mi formaldehyde increase.

No significant differences in fuel economy were observed with the base-line and the blended fuel (see Tables VI and VII). Although it might be anticipated that lower fuel economy would result with the blended fuel because of its lower specific heat content, this trend is not evident here.

A comparison of the HC composition taken from FTP exhaust emissions data is graphically summarized in Figure 2. Results for the Cavalier, though not dipicted, are similar to those presented for the Mustang. Detailed HC emissions appear not to be significantly affected by the shift from base-line to blended fuel usage. This observation was also noted at the other driving cycles examined.

Blended Fuel Evaporative Emissions

Diurnal and hot soak evaporative emissions data were obtained with the base-line and blended fuel. Exception to the test sequence given in Table IV was made during a portion of testing on the Mustang to develop a better understanding of the factors affecting evaporative emission control.

Evaporative emissions from the Mustang are charted in Figure 3. With the base-line fuel, emissions appeared in compliance with the standard, even though Reid vapor pressure (Rvp) of the fuel (11.7 psi) exceeded the maximum Rvp level (9.2 psi) specified in the *Federal Register* test procedure.[12] After three tests, diurnal and hot soak emissions averaged 0.1 g and 0.2 g, respectively. In these tests with the base-line fuel, the evaporative emissions test sequence, as given in the *Federal Register*, was followed. However, between each evaporative test sequence, four driving schedules were run (HFET, NYCC, SCC-12, and SCC-36).

A shift to blended fuel was made after the base-line fuel had been examined, and evaporative testing continued. During the initial diurnal test with blended fuel, canister breakthrough occurred and emissions reached 12.9 g. Hot soak emissions for this run, which measured 0.2 g, appeared unaffected by blended fuel usage.

Prior to the second test on blended fuel, the canister was removed from the car and mechanically purged by a small blower. Purging took place over a 12-h period. After replacement of the canister, the car was run through an HFET, NYCC, SCC-12, and SCC-36 sequence before the evaporative test sequence was followed. Diurnal and hot soak losses measured 0.68 g and 0.43 g, respectively. Thus, diurnal evaporative emissions decreased as a consequence of the mechanical purge and/or the extended purge which had occurred during the four runs preceding the test.

The third, fourth, and fifth evaporative tests with the blended fuel were run back to back. That is, the HFET, NYCC, SCC-12, and SCC-36 were not run between the evaporative test sequences. Evaporative emissions for the third and fourth tests remained low, although canister breakthrough was observed at the end of the fourth test. On the fifth test, breakthrough occurred early in the diurnal test and emissions exceeded 17 g. Hot soak emissions, which appeared relatively insensitive to fuel usage and run sequence, always remained below 0.6 g for both cars.

After the fifth test, the remaining three tests were conducted so that each was preceded by HFET, NYCC, SCC-12, and SCC-36 driving schedules. Combined diurnal and hot soak emis-

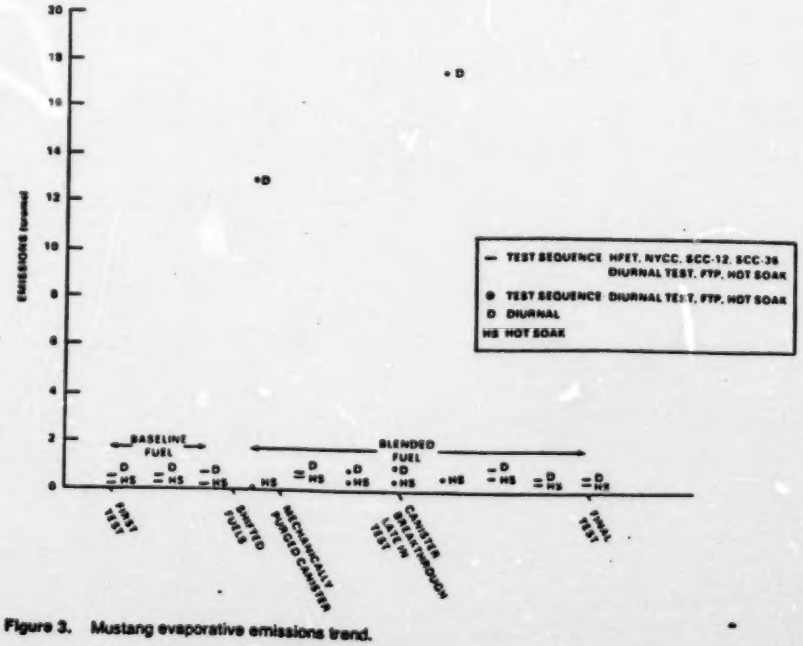

Figure 3. Mustang evaporative emissions trend.

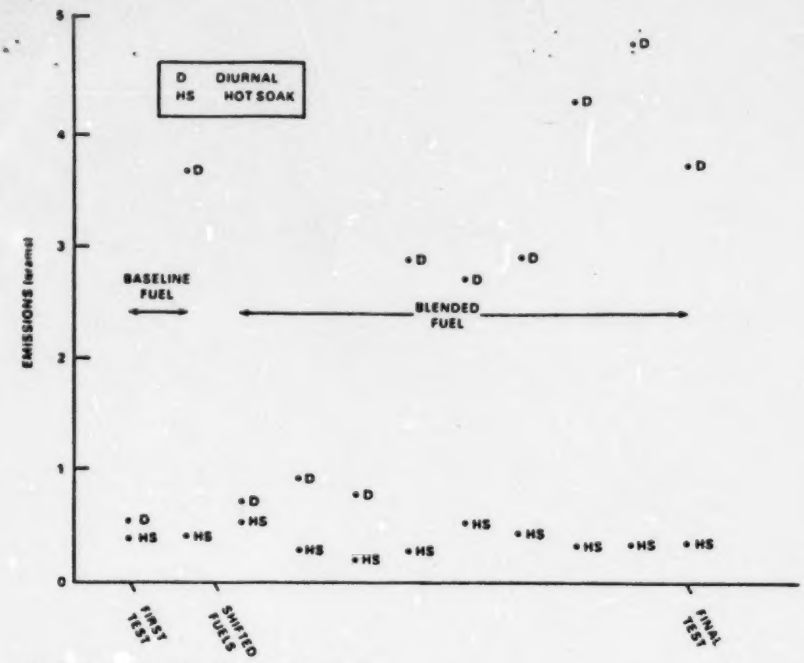

Figure 4. Cavalier evaporative emissions trend.

sions again averaged less than 1 g for each of these tests.

Increased emissions observed during diurnal testing of the Mustang may be attributed in part to the higher Rvp of the blended fuel. A relationship is also apparent between purge period for the canister and diurnal emissions. Whenever the diurnal tests is preceded by an HFET, NYCC, SCC-12, and SCC-36 sequence, the evaporative emissions are low, regardless of test fuel. But breakthrough occurs when the evaporative tests are preceded by only Test Phase 3 of the FTP.

In a recent study[1] aimed at evaluating the effects of methanol-hydrocarbon blends on charcoal, hydrocarbon breakthrough times were found to be reduced 20 to 44 percent with the methanol blends. Working capacities of charcoal were also found to be reduced from 10 to 52 percent with the methanol blend. Although breakthrough emissions from the Mustang cannot be entirely attributed to use of the methanol blend, use of the blend, based on results of the above study, contributes substantially to these high emissions. Other investigators have reported higher evaporative emissions with alcohol blended fuels, even when the blends were prepared to match the distillation properties of base gasoline.[16,19]

Evaporative emissions testing on the Cavalier with the same two fuels yielded less definitive results (see Figure 4). Emissions were low (<1 g, combined diurnal and hot soak) during the initial test with base-line fuel. However, diurnal emissions exceeded 3 g on the following day. After base-line fuel was replaced with blended fuel, diurnal emissions fell to about 0.7 g. These remained between 0.7 g and 0.9 g for two successive tests, then increased to levels between 2.5 g and 5.0 g for the six final days of testing. Hot soak emissions remained at levels below 0.6 g for all tests performed on the Cavalier.

All evaporative testing of the Cavalier was performed using the repetitive sequence given in Table IV (diurnal, FTP, hot soak). Following weekends or breaks in testing, the vehicle was prepared on the day before testing by refueling and running an FTP.

Available Cavalier data provide no explanation for the decrease in diurnal emissions immediately following the shift to blended fuel. Increases noted in diurnal emissions both with gasoline and with the blended fuel may be related to insufficient canister purge. As with the evaporative tests on the Mustang, an extended study simulating vehicle operation in customer service is required to obtain more realistic emissions rate data and to better evaluate the relationship between canister purge time and evaporative emissions with methanol blends.

Evaporative emissions measurements of detailed hydrocarbon composition were obtained for the Cavalier and Mustang. Except for the diurnal emissions when breakthrough occurred, there were no statistically significant differences in the hydrocarbon composition resulting from use of the base-line or the blended fuel. *N*-butane, toluene, isopentane, and other volatile gasoline components dominated these emissions. For the diurnal tests where breakthrough occurred, *n*-butane usually comprised around 70% of the total emissions versus an average of about 25% for the other tests. Only small, barely detectable quantities of methanol were present in about 15% of the tests run with the blended fuel.

Methanol Car Exhaust Emissions

The regulated exhaust emissions (HC, CO, and NO_x) and fuel economy summary for the Methanol Escort are given in Table VIII. Means, standard deviations, and number of tests are given for each of the five driving cycles examined. The organic emissions are presented as non-methanol hydrocarbons.

The data indicate that Escort CO emissions exceed the standard level (3.4 g/mi). When the vehicle was first tested by EPA-Ann Arbor, its emissions were in compliance with standard levels. However, following delivery to EPA-RTP and later repairs (see Vehicle Description section), its emissions

Table VIII. Escort regulated exhaust emissions and fuel economy summary.

Cycle		Non-methanol HC (g/mi)	CO (g/mi)	NO_x (g/mi)	MPG (mi/gal)
FTP	$\bar{X}$	0.21	5.94	0.96	15.20
	s	0.09	0.93	0.08	0.32
	n	11	12	12	12
HFET	$\bar{X}$	0.04	0.89	1.12	22.18
	s	0.02	0.36	0.08	0.44
	n	6	6	6	6
NYCC	$\bar{X}$	0.28	2.84	1.52	7.73
	s	0.10	0.88	0.20	0.12
	n	5	5	5	5
SCC-12	$\bar{X}$	1.02	19.94	1.42	11.41
	s	0.22	1.46	0.10	0.33
	n	6	6	6	6
SCC-36	$\bar{X}$	0.10	3.00	0.99	20.27
	s	0.02	0.80	0.05	0.63
	n	6	6	6	6

Table IX. Escort methanol and formaldehyde exhaust emissions summary.

Cycle		MeOH (g/mi)	Aldehydes (mg/mi)
FTP	$\bar{X}$	0.79	38.5
	s	0.18	3.0
	n	11	8
HFET	$\bar{X}$	0.12	16.6
	s	0.14	4.6
	n	6	4
NYCC	$\bar{X}$	0.10	19.6
	s	0.08	8.6
	n	5	4
SCC-12	$\bar{X}$	3.01	194.4
	s	0.68	11.6
	n	6	5
SCC-36	$\bar{X}$	0.20	24.5
	s	0.02	3.4
	n	6	5

remained somewhat elevated.

Methanol and formaldehyde exhaust emissions are given in Table IX. Means, standard deviations, and number of tests are given for each of the five driving cycles examined. In general, methanol emission rates are higher than non-methanol HC emission rates by a factor of 3. Aldehydes are roughly an order of magnitude higher than those from gasoline-fueled automobiles. Of the total aldehydes measured, more than 95% are emitted as formaldehyde. When aldehyde and methanol emission rates are ranked by test cycle, a correlation is observed between emission of the two pollutants. Methanol emissions by test cycle proceed: SCC-12 $\gg$ FTP > SCC-36 > HFET $\cong$ NYCC; and aldehyde emissions proceed similarly: SCC-12 $\gg$ FTP > SCC-36 > NYCC $\cong$ HFET. This trend bears out the notion that methanol, a partially oxidized species itself, can readily undergo reaction to give formaldehyde. This tendency has been noted by other investigators in experiments with methanol blends.[20]

Detailed hydrocarbon measurements made in Escort exhaust gas are similar in composition to those from the gasoline-powered vehicles (see Figure 2). These hydrocarbons are probably derived from combustion products and the gasoline fraction of the fuel. On the average, 65% of the hydrocarbons are paraffins, 25% are aromatics, and 10% are olefins. Methane is the highest single HC component emitted in each test cycle examined. In the FTP, methane comprised about 30% of the total HC emitted.

Methanol Car Evaporative Emissions

Escort evaporative emissions are summarized in Table X, which separately presents non-methanol HC and methanol emissions. Diurnal and hot soak emissions are about 40% and 65% methanol, respectively. The composition of diurnal non-methanol HC contains 53% paraffins, 6% aromatics, and 41% olefins. Composition of the hot soak non-methanol HC, similar to those for the Cavalier and Mustang hot soak emissions, is 65% paraffins, 20% aromatics, and 14% olefins.

Total evaporative losses from the Escort are somewhat higher than those from the Mustang and Cavalier, excluding tests where breakthrough occurred with the latter vehicles. Hot soak emissions, which contain mostly methanol, are higher than diurnal emissions, and approach levels measured from the Mustang and Cavalier when the methanol fraction is subtracted.

Table X. Escort evaporative emissions summary.

Test type		Non-methanol HC (g)	Methanol (g)
Diurnal	$\bar{X}$	0.36	0.22
	s	0.22	0.06
	n	8	6
Hot soak	$\bar{X}$	0.65	1.24
	s	0.19	0.39
	n	7	6

Conclusions

Results obtained in this study support the following conclusions:

1. For the base-line and blended fuels examined, statistically significant differences in regulated emissions occur only during tests on the NYCC, which resulted in 30% higher NO_x emissions with the blended fuel usage.
2. FTP aldehyde emissions exhibit a statistically significant 50% increase over base-line level with the blended fuel usage.
3. About 80% of the increase in aldehyde emissions with the blended fuel usage is attributed to an accompanying increase in formaldehyde emissions.
4. Increased diurnal evaporative emissions observed with the blended fuel usage appear to be related primarily to canister purge time.
5. *N*-butane usually comprises about 70% of the total hydrocarbon losses for diurnal tests with the blended fuel when breakthrough occurs.
6. FTP aldehyde emissions from the Methanol Escort are about 40 mg/mi, roughly an order of magnitude higher than those from the Cavalier operating on the blended fuel.
7. Of the total aldehydes measured from Methanol Escort exhaust gas, more than 95% are emitted as formaldehyde.
8. Methanol emissions from the Methanol Escort are about 0.8 g/mi for the FTP, and good correlation appears between methanol and aldehyde emissions rates.
9. Methanol Escort non-methanol hydrocarbon exhaust emissions are composed similarly to those from gasoline-powered vehicles.
10. Evaporative losses from the Methanol Escort averaged 2.5 g per test (diurnal + hot soak), with methanol comprising about 60% of the total loss.

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